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DESERT SURVIVAL AND THE FUNCTIONS OF ABORIGINAL NOMADS IN THE SUMMER DESERT

Each year Europeans die in the desert during summer after 4 to 8 hours exposure to heated air and sun. Circulatory failure and heat exhaustion follow attempts to walk without water in the sun.

Aborigines* survive in the desert by a combination of behavioural and physiological adjustments. They have had minimal protection, over the 35,000 or more years of hot dry or the hot wet summers they have lived through in Australia. But the stick and leaf canopy of the wiltja (shelter) is orientated east-west to exclude the sun, while the constant desert wind gives convective cooling through the open ground level supports of the structure. There the nomads sleep through the hot hours of the day, near a water hole. Hunting is undertaken in the morning or evening and a largely carnivorous diet provides 70% of water with the food - as among the desert marsupial dasyurids who share the habitat. Journeys are made in summer by night if water supplies fail. Apart, however, from the observations of Wardlaw, Davies & Joseph (1934), Davies (1935) and Wardlaw (1935) there is very little information on the summer functions of Aborigines. This is understandable enough since much of the earlier investigation took place during May or August University vacations. The desert in summer is both uncomfortable and dangerous. The dust, flies, heat and aridity of the arid centre have discouraged anthropological intrusion. But at H[illegible]berg Mission in January 1933 Wardlaw et al. (1934) studied 1 Aluritja and 3 [illegible] men. The observers concluded that a 2-hour walk at 35°C induced 35% mor[illegible]r loss per m^2 in one Aboriginal man than in the Europeans. Clothes reduced the sweating of both groups, in the sun, and there was a greater increase of evaporative loss in Aborigines without clothes, than among the Europeans. This finding was not followed further. Hicks and Moore (1934) recorded a desert walk during which Aborigines did not drink, but later they drank twice as much water as Europeans, however.

In winter, physiological measurements were made from 1932 on Aboriginal groups of different levels of acculturation. These studies showed that blood pressure rose with increasing levels of European contact (Nye, 1937, van Dongen, Davidongs and Abbie, 1962) and that metabolic rate was generally lower in Aborigines than in Europeans (Hicks, Moore & Eldridge, 1934). The ability of Aborigines to sleep naked beside fires during winter, (reported by Hicks, 1938), was followed up by Scholander et al. (1958) who confirmed the finding that at night, cold feet did not cause the subjects to wake nor did the cold skin lead to shivering like that of Europeans in the same environment. By 1958, Scholander and his colleagues had difficulty in persuading Aborigines to remove their clothes for sleeping, but in the desert they still retained the neurological mechanism which allowed cold skin and sleep to co-exist. Habituation of the nervous system to cold (Glaser, 1966, Macfarlane, 1964) was less complete in tropical Aborigines of Arnhem Land than in Aruntas exposed to the winter temperatures of the desert. Hammel et al. (1959) measured the response of Aboriginal and European men to 0.5°C and found that the tropical Aborigines shivered and raised metabolism more than desert men, but less than Europeans.

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* Aborigines, -um, m.pl. The original inhabitants of a country.

In the Weipa area of Cape York Peninsula, Wyndham, McPherson and Munro (1964) measured responses of tropical subjects to humid heat. They compared European and Aboriginal sweating and heart rates in the saturated environment of plastic tents kept at 32°C. In this situation the Aborigines produced about half as much sweat as well-acclimatised Europeans. This was interpreted as a lack of Aboriginal acclimatisation to tropical heat.

The approach used in the present investigations was that of comparing the use and handling of water and electrolytes by Aborigines with that of Europeans of the research group, working together at the same time and place (Macfarlane, 1969). Although this method has limitations, the desert provides sun, heat and dust to the groups being studied, in a way that cannot easily be reproduced in the laboratory. European levels of heat acclimatisation would not equal those of the Aborigines but all the Europeans had been exposed to many summers in Australia. They were physically fit, and covered the age range of the Aborigines.

<u>Groups studied</u>

Four different sets of subjects were investigated during different years. The levels of European contact by tribal groups were low in the initial studies, but acculturation was greater in subsequent investigations.

1. Ngadadjara nomads were the least influenced by Europeans. They camped on the plain near the waterhold of Kudjuntari, (lat. 25°S) near the eastern end of the Rawlinson Ranges in Western Australia, and were studied in November 1963. This region is between the Gibson and Victoria deserts. Already more than 4 years of the long drought (which ended in 1966) had passed so that there was little grass and much of the mulga (<u>Acacia aneura</u>) was dead or dying. Three extended families, a total of 25 people, camped in the mulga-spinifex association and hunted kangaroos to a distance of about 8 km from the waterhole. Water was carried by the women each day from the waterhole 3 km distant from the camp area. The camp was away from the water so that kangaroos could come to water and could be hunted. These Ngadadjaras rarely saw white men and they lived off the country. They traded dingo scalps to Missions and Welfare stations 500 to 700 km distant, exchanging scalps for clothing, axes, water containers and 0.22 calibre rifles. They remained expert with spears, however, and manufactured spears, spear-throwers and resin-hafted chisels. Much of their interest and activity was concerned with ritual, the singing of sacred songs and the preparation for the drama corroborees.

2. Pitjandjadjaras, camped on the arid plain near Kalkar (Mt. Davies) in the Peterman Ranges were also studied in 1963 before they moved to the welfare station 230 km distant. These 32 people had had more contact with white man than the Ngadadjaras and mining exploration in the area had exposed them to the use of money. They hunted wallabies and rabbits but they also received flour and treacle brought each 2 weeks from Musgrave Park. The religious observances were fewer and less strict than those amongst the Ngadadjaras, but they undertook Warapiti ceremonies for wallaby increase when they passed the ceremonial area.

These people in 1964, moved with other Pitjandjadjaras to the Musgrave Park Welfare Station since the region became depleted of kangaroos as the drought

continued. Camps were set up peripherally to the Station. At this Station work was undertaken for wages by some of the men. They spent this on tools and food, including up to 4 kg sugar per man week. The rest occupied much of their time with corroborees and ceremonial shared with tribes from the north. Observations and physiological measurements were continued in 1966 on these people who had earlier lived in the desert at Kalkar. A group of them moved 40 km out into the desert for the period of study.

3. Pintubi, originally from the west (Canning stock route area) had been moved to Papunya (lat. 22°S) in 1965 towards the end of the 8-year drought. Many of these people died of infection within the first year of contact in the settlement with the Walbri tribe and Europeans. A residue of the Pintubi went to live in the spinifex desert 80 km from Papunya at a water-source, Warawiya, a barren area near Mt. Liebig. These people were compared with the other groups and with Europeans in January 1969. At that time they had had more than 3 years contact with settlement, had learned something about money, acquired tastes for flour, sugar and alcohol and had lost much of their interest in song, ritual and dance. The main interest of the men was hunting wallaby, kangaroo, and the occasional wild cat. The women gathered seeds, lizards and ants. Social disintegration had been considerable, especially since the high mortality, quarrels with unfamiliar tribes, and displacement from sacred grounds, had taken place over more than 3 years. There were quarrels over money, women and leadership.

4. Dalbon people of central Arnhem Land were studied in January 1971 (lat. 13°S). They oscillated between two social patterns. During winter months they lived on their tribal lands hunting and gathering food as well as performing religious ceremonies. During the summer many of them took up residence in houses, shacks or wurlies at the Bamyili government settlement and ate European food. They slept on concrete floors and learned to drink canned beer at tables. When this was no longer of interest they moved back to the bush. All of these people had European equipment, talked English and had some sophistication in the use of money and alcohol. The older men could not control the young who took excessive amounts of alcohol. The Dalbon had, however, lived in the Arnhem Land wet tropics throughout their lives, so they provided an interesting contrast with desert peoples.

In all of these environments the daily temperatures were high but not extreme. In the desert the usual range was from 34 to 42°C with low humidities, while in Arnhem Land temperatures were between 30 and 36° daily with humidities at the time of maximum temperature between 40 and 70%. Summer rains fell in Arnhem Land during the studies.

Measurements

The main measurements made were of height and weight with estimates of age, extracellular fluid volume, plasma and total body water, together with rates of sweating. The sweating rate was derived from weight change as well as from collection of arm sweat in a plastic bag. Skin temperatures and reflectances were measured. The effects on urine flow of drinking a measured load of water was compared with the effects of deprivation of water during a summer day and of walking across the desert in the sun clothed (Aborigines and Europeans) in shirt

and trousers. Water ingestion was measured by timing the rate of drinking from a 1 ℓ. vessel.

Total body water was measured initially by the dilution of 25 ml of D_2O taken by mouth. Later 300 μCi of TOH by mouth was employed in the Northern Territory, and in addition to the volume of water, the rate of turnover of water was obtained as an integral, by measurements of urine protium : tritium ratio over 2 weeks.

Extracellular volume. An injection of 15 mg/kg sodium thiocyanate was given intravenously together with 4 mg/kg of the dye T1824. This was used to estimate the volumes of the plasma and extracellular spaces.

Measured water loads of 12 ml/kg body weight were taken by mouth and the rate of excretion of this water was compared in Aboriginal and European subjects side by side. The rate of water, sodium and potassium output was estimated from the timed samples.

Dehydration during 9 hr, through the heat of the day was followed by timed urinary collection and blood sampling. Sweat was collected in an arm-bag taped at the mid-point of the upper arm, during a period of 1 hr walking in the sun. The volume of sweat and the sodium and potassium secretion rates were estimated by flame photometry.

The sodium and potassium concentrations in urine were determined on samples collected after walking for one hour in the sun. At the same time the changes in body weight occurring at hourly intervals throughout the day were measured with a balance reading to 20 g, and checked for calibration at each weighing. The Aborigines walked or spent the time with Europeans so that casual emptying of bladder or rectum was prevented.

Timed samples of saliva were collected without stimulation for comparison with electrolyte distribution in the sweat and urine. Cardiovascular function in the heat was assessed in terms of changes of pulse rate and blood pressure immediately before and for 10 min after a period of stepping up and down 30 cm 150 times in 5 minutes during the afternoon heat.

Estimations of plasma electrolyte, urea, haemoglobin and renin concentrations were made. Arterial blood pressure was measured in subjects sitting at rest and changes of pressure and pulse rate during and after standard exercise. Salivary electrolyte concentrations were compared with those of sweat and urine in Europeans and Aborigines working together in the same environment.

Sweat suppression was studied by arm bag, using both arms. A bag remained on the right arm for 2 hours, while the bag on the left arm was removed for 30 min each half hour.

Results

Skin temperatures. In the shade the temperature of arm, hand and face skin of both white and Aboriginal men was in the same range.

In the sun both Ngadadjara and Pitjandjadjara skins were 1 to 3° hotter than those of Europeans sitting beside them, at air temperatures between 30 and 39°C. The forearm skin measured with thin mercury thermometers or with thermistors was hotter than that of white subjects. The difference was maintained when the thermometers were shaded and moved quickly onto the zone which was fully irradiated by the sun. Reflectance in the visible range was 3 times greater for whites than blacks, and total radiation from white skin averaged 26% - 31% more ergs/cm^2/sec than from black skin. At an air temperature of 33°C D.B. in the sun at noon, arm skin temperatures averaged 38.8°C for Europeans and 40.3°C for Aborigines.

During rest there was no difference between the oral temperatures of the European and Aboriginal men, nor were there differences following moderate exercise (Table 1).

Water metabolism

Intake and turnover. Among Ngadadjara and Pitjandjadjaras water was taken shortly after dawn and in the evening when the women brought in supplies. If water became available during the heat of the day it was readily accepted and very rapidly ingested. The rate of drinking was fast in all Aboriginal groups studied but the desert tribesmen ingested water more rapidly than the Arnhem Land people. During cool weather in the desert Ngadadjaras drank 2% of body weight in between 10 and 35 sec (an average of 17 sec/ℓ.) while Europeans in the same circumstances found it difficult to drink more than 0.7 ℓ. and ingested 2% of body weight in an average time of 156 sec (100 sec/ℓ.). At the end of a hot day without drinking Aborigines drank 1 ℓ. in 13 sec while Europeans swallowed the same volume in 30 sec. Six Pitjandjadjara men drank 2% of body weight in 14 - 25 sec (19 sec average) while the Europeans took 165 sec. During cooler weather (28°C) 6 Pintubi men drank 1 ℓ. in 15-25 sec (average 19 sec) and 4 drank 2 ℓ. in 34 to 39 sec (average 36 sec) but 2 took only 1.6 ℓ. in 53 sec. Europeans drank 0.5 ℓ. in 36 sec but found it more difficult and unpleasant. The Europeans could not ingest 2 ℓ. in rapid sequence. Amongst the Dalbon men, at air temperatures between 32 and 35°C, water equal to 2% of body weight was ingested in 14 to 65 sec (average 38 sec) compared with 83 sec among the Europeans. In the heat 10 Dalbon men drank 1 ℓ. in an average time of 24 sec while Europeans required 38 sec just after noon at an air temperature of 36°C.

All these Aboriginal groups had skill in rapid swallowing of water whether unflavoured or flavoured with lemon or taken in the form of tea. The children were also able to swallow very fast. This facility in water ingestion is used when Aborigines are going hunting since they take a large quantity, between 1 and 2 ℓ., then set off across the desert.

Water distribution. The extracellular fluid volumes of Ngadadjara and Pitjandjadjara men were greater than those of Europeans in the same environment. Extracellular fluid in 6 Ngadadjaras averaged 28.3% of body weight, in Pitjandjadjaras (8) it averaged 25% of body weight and among the Europeans (4), 19.8% of body weight. The desert people and those in Arnhem Land were all relatively lean. Some Aborigines on welfare stations become extremely fat but this had not happened to any of the nomadic subjects used in these measurements. Amongst the Pintubi who were the least lean of the people studied, total body water averaged 66% compared with Europeans at 62% of body weight. The body water of Arnhem Land Dalbon males averaged 69.4%, relative to

61.8% of body weight in Europeans. There was thus relatively more extracellular volume and more total body water available in Aborigines than in Europeans.

Water output.

1. Urine volume and concentration. Complete daily collection of urine from people camped in wiltjas over a wide area was not possible. Overnight urine was collected at dawn, however, from men, women and children. Nights in the desert were often very hot with the air temperature remaining at 30° after midnight. Dawn urines amongst Aborigines were pale in colour, low in concentration and high in volume, and frequently reached 700 ml : whereas Europeans averaged 280 ml and rarely produced 300 ml of urine overnight. The urine was yellow and of greater concentration than that of Aborigines. European urinary osmotic pressures were regularly greater than those of Aborigines.

In Arnhem Land the differences were not so great as in the desert but Aboriginal urinary concentration was lower and volume higher than from the Europeans in the same environment.

2. Water loading. During cool weather with air temperatures reaching 25°C the rate of flow of urine from Aborigines was 2 to 3 times higher than that of Europeans at the same time of day. When a standard water load of 20 ml/kg was ingested several patterns of response were found. Amongst Ngadadjara men this load of water did not significantly affect the rate of urine flow but in Europeans it caused a rapid diuresis. Pitjandjadjara (Table II) and Pintubi varied, some increasing diuresis, while others were unaffected by the added load. In Arnhem Land a water load in relatively cool weather resulted in a similar diuresis among both Aboriginal and European groups.

During hot weather with temperatures of 35°C or more, water ingested at the rate of 20 ml/kg induced a diuresis in Pitjandjadjara and Pintubi in the desert. They consumed large amounts of water in the morning and had flow rates 5 to 10 times greater than Europeans between 7 and 10 a.m. An additional load of 20 ml/kg was excreted within 3 hours, whereas less than one third of the load was put out in that time by Europeans. Water loading in the humid heat of Arnhem Land produced similar rates of excretion in both groups.

Water deprivation. Subjects drank to satisfy thirst with water or tea between dawn and 7 a.m. then took no further fluid until 5 p.m. during tests made in all the environments. In the desert, temperatures ranged from 35 to 42°C and sweating at rest began by 9 a.m. In the course of the day 2 or 3 walks each lasting 1 hr (5 km) were taken in the sun across the desert (Table III).

The early morning urine flow rates of Aborigines during hot weather were greater than those of Europeans (Table IV). These rates fell as dehydration progressed and the European rates remained lower than those of Aborigines. The reduction in urine flow rate amongst Ngadadjara men was less than that shown by Pitjandjadjara or Pintubi and it was gradual in all. The European urinary response, however, was one of rapid reduction in urine volume by 70 - 80% in both desert and tropical environments.

The excretion of sodium, however, differed more than the water handling. The Ngadadjaras increased sodium output and the rate of sodium excretion during days of water deprivation. Potassium, also, was excreted more by the Ngadadjaras and the Pitjandjadjaras, during a day without water. Amongst Europeans, however, sodium retention began promptly before noon as sweating commenced and both sodium and potassium were retained by the kidneys. In Arnhem Land the differences were less marked, though urine flow rates were initially about 4 times higher in Aborigines than in Europeans and during a period of exposure to heat and exercise the Dalbon rate remained at twice that of the Europeans - although rates were reduced in both groups. After the exercise, diuresis began again in the Aborigines but Europeans continued to retain water by a reduced flow rate. With sodium excretion a similar pattern occurred. The European output was reduced to half while walking in the Arnhem Land heat, but Aboriginal sodium output was reduced only 18% and did not change after the exercise, while European sodium output fell to one quarter of the initial rate during recovery. Potassium excretion fell then rose in both groups.

During the day-without-water experiments the differences between Aborigines and Europeans were greatest in the Ngadadjaras, less in the Pintubi and least in the Arnhem Land people (Table V). The same overall pattern, however, was present. That is, Aboriginal rates of excretion of water were high initially and although they were reduced during work in the heat, when this stopped there was still water to spare and urine flow rates increased again. This did not occur in Europeans who continued to reduce water loss even when resting.

After such a day of thirst and sweating the Aborigines overnight replaced 90% of the weight lost, whereas the Europeans on the average replaced only 56% of the fluid lost on the previous day.

<u>Sweating</u>. Estimates of the rate of sweating were made by taking serial body weights during periods when urine and faecal losses were either measurable or not occurring. Loss of body weight represents, however, not only sweat loss but also a small component of transpiration and carbon dioxide loss from the respiratory tract. Since the metabolic rate of Aborigines has been reported to be lower than that of Europeans (Hicks et al. 1934, Wardlaw et al. 1934) these losses should be proportionally smaller than those of Europeans. A second measure of sweating was obtained by placing a plastic bag on the arm so that it enclosed an area downwards from the middle of the upper arm. The skin areas of this zone were estimated from length and diameter of the arm components. Areas proportional to body weight.

Whole body sweating per kilogram of body weight was greater in Ngadadjara than European males, but the arm bag sweat collected over an hour was only 21% of the volume, and the sodium concentration only 40% of that of the Europeans (Table VII). Urea reached 40.1 mmol/ℓ. in Ngadadjara sweat compared with 18.0 mmol/ℓ. from Europeans. The Pitjandjadjara rates of sweating into armbags were twice those of Ngadadjaras and the sodium was a little more concentrated, but these men still suppressed sweat to twice the extent of Europeans. These Pitjandjadjara people had more European contact than the Ngadadjaras.

By body weight change the desert Pintubi produced sweat at twice the rate of Europeans in the same environment. During walks across the desert in the sun with air temperatures between 35 and 38^{o}C the Pintubi lost sweat at the rate

of 13.6 ml/kg/hr compared with Europeans sweating at the rate of 6.5 ml/kg/hr. The ratio of European to Pintubi sweating (as ml/kg/hr) was 1:2.1 for whole body sweat by weight, and 1:0.6 from the armbag collections. Both groups wore clothes to cover essentially the same areas of skin so that heating by radiation was the same. Oral temperatures were also almost identical in the two groups (Table I). In Arnhem Land the sweating rate from the whole body was only 15-32% greater in the Aborigines than in Europeans walking with them. In another measurement 10 Dalbon men produced 10.6 ml/kg/hr of body sweat compared with 7.0 ml/kg/hr by Europeans (51% difference).

Sweat collected in the arm bags at slower rates amongst Aborigines than from Europeans. When collections were made in the desert during an hour, the lowest volumes were found in the Ngadadjaras, about twice as much in Pitjandjadjaras and more again in Pintubi, but still less than that accumulated in the arm bags of Europeans. In Arnhem Land (Table VI) there was a 13 to 58% greater sweating rate in the arm bag of Europeans than Aboriginals in a series of 5 measurements.

Sweat sodium and potassium concentrations also differed amongst the groups. The lowest sodium and highest potassium concentrations were in the Ngadadjara, sodium increased in Pitjandjadjara to about half the European levels, they were greater again in the Dalbon and highest in the Pintubi. Potassium changed less than sodium in this sweat. Even the Pintubi, however, had sodium concentrations only half those of Europeans in the same environment. Both the desert and the tropically adapted Aborigines secreted sweat with lower concentrations of sodium than Europeans, as would be expected from greater acclimatisation to heat. But there was massive suppression of sweating when Aboriginal skin was exposed to the saturated environment in an arm bag.

Experiments to determine more details of the rate of suppression were undertaken in Arnhem Land and in the laboratory. By putting bags on both arms and removing one bag after 30 min while the other remained in place, a series of measurements of the effects of continuous and discontinuous exposure to hot saturated air was obtained. With continuous exposure the European rate of sweating fell to half in 90 min and the Aboriginal rate to 1/13th the initial rate in the same time (Table VI). With discontinuous use of the arm bag there was a small increase in European arm bag sweat rate after 30 min freedom from this environment, while Aboriginal arm bag collections were depressed 30% in spite of 30 min for recovery of sweating between samples. The concentration of electrolytes was little affected in either group by the rate of secretion, except that when European flow rates were very high the sodium content also rose. The degree of sweat suppression in children was even faster and more marked than that in adults when the arms were enclosed in a plastic bag. Amongst Aborigines studied in the laboratory (and part-Aborigines who had been away from desert or tropics for some time) a rapid rate of suppression was found also. Under different environmental conditions the time for suppression of sweating to reduce the flow to half for Europeans was 45 min, Aborigines 25; European 75 min, Aborigines 25 and European 27 min, Aborigines 12 min, during tests lasting one hour. In measurements over 15 or 30 min the half-time of suppression was even faster for Aborigines. Among Aboriginal children under 10 the suppression time was even faster.

Water turnover. The most satisfactory measurements were obtained on Pintubi and Dalbon people in the Northern Territory. Amongst Pintubi males the average turn-

over during 12 days was 3.4 ℓ. compared with 5.4 ℓ. amongst the Europeans (who weighed one third more than Aborigines). Lactating women averaged 5.8 ℓ. daily - a rate of 124 ml/kg/24 hr. When adjusted for weight the Pintubi males averaged 94 ml/kg/24 hr compared with the European average of 54 ml/kg/24 hr. This period of observation was interrupted by 4 days of cool weather so that the average turnover was considerably below the rate that might occur during a heat-wave. Amongst the Dalbon in Arnhem Land the turnover rate for water was 190 ml/kg/24 hr for adult Aborigines and 80 ml/kg/24 hr for Europeans in the same environment, while native children used 176 ml/kg/24 hr in the humid tropics during summer. The rate of 190 ml/kg/24 hr is near that of European cane cutters working maximally in summer. Yet the Dalbon men were taking only mild exercise - the short walks accompanied by the Europeans.

Exercise tolerance. Survival in the desert is largely determined by the maintenance of adequate circulation, when body fluids are being reduced by sweating. Most of the desert people still have low arterial pressures, but these climb with acculturation. The Ngadadjara (male) pressures were all below $^{108}/_{78}$ mmHg, 9 Pitjandjadjara were $^{96}/_{50}$ - $^{138}/_{82}$ ($^{108}/_{67}$) but among 6 Pintubi, after 3 years exposure to the desert welfare station the pressures ranged from $^{100}/_{60}$ to $^{130}/_{95}$ ($^{113}/_{76}$), and 12 Dalbon adult men were in the range $^{114}/_{74}$ -$^{138}/_{88}$ ($^{126}/_{78}$). But the Dalbon children (4-9 yr) were lower, at $^{90}/_{72}$ to $^{96}/_{60}$ mmHg.

Standard exercise (of 150 steps up 30 cm) produced smaller rises of Aboriginal pulse rate and blood pressure than of European responses tested at the same time (Table I). The Aborigines appeared thus to be more physically fit than the Europeans, and presumably they would have better cardiovascular reserves for desert journeys than the Europeans. Recovery from exercise in the heat of the afternoon resulted in lower diastolic pressures in the Europeans than Aborigines, probably because of greater vasodilation. In both groups, however, the plasma volume increased as a result of exercise without water and there was a fall of 1.5% in packed cell volume. Sedimentation rates rose in both groups. In neither group was the degree of dehydration (about 3% weight loss) sufficient to reduce plasma volume, but rather fluid was retained in the circulating space almost equally. Plasma renin levels were 2 or 3 times greater in the Aborigines than Europeans

Discussion

In these investigations there were two main variables. One derived from habitat, varying from desert in summer during drought, to the wet tropics in summer rain. The other was concerned with differing degrees of European contact and acculturation. This ranged from the nomadic hunting groups of Ngadadjara, to the Dalbon who were housed and fed on a welfare station. Some components of these undoubtedly influenced the physiological status of the different groups. The method of comparing Aboriginal functions with that of Europeans in the same environment has its difficulties since the groups of European were small (4 to 6 males) and although their food was high in animal protein like that of the Aborigines the dietaries differed in items such as coffee and canned fruit which were not usually taken by the Aborigines. The Europeans were acclimatised to Australian summer conditions but had not lived continuously in the desert or the tropics. So they formed a useful reference point for the impact of sun and air temperature on both groups, but the Europeans had been exposed to different environmental conditioning from that of Aborigines.

Temperature. The absorption of solar radiation by black skin was greater in still air than that of white skin. This led to a skin temperature differential of 1-3°C which was reduced when wind convection was increased. Wardlaw (1934) made some observations on skin temperature and had postulated that it would be higher in Aborigines. The measurements made by Goldby, Hicks, O'Connor and Sinclair (1938) were taken during winter and sometimes in tents, so the radiation component was small. In the sun, greater absorption of radiant energy in the visible region of the spectrum, by Aboriginal skin appears to be compensated by a greater rate of sweating. The skin sensations presumably have been habituated (Glaser, 1966) to the level where no sensation of increased heat is induced.

Resting oral temperatures during the summer were in the same range for black and white subjects. After exercise the Aboriginal oral temperatures were 0.1°C lower than before 5 minutes of work while the white temperatures were virtually unchanged - probably because of the respiratory cooling of the mouth region during work. Similar findings were made before and after walking in the desert, where heat balance was maintained in both groups, at the work levels undertaken. If more strenuous exercise had been performed possibly greater differentials could have been observed. The Aborigines, however, were reluctant to work hard during the heat of the day: their usual pattern was that of resting or sleeping in the shade while the sun was high but they moved fast during the hunt in the cooler parts of the day. When walks were taken across the desert between 11 a.m. and 4 p.m. the white and Aboriginal subjects wore clothes and were similarly protected from direct radiation, so that differences in sweat rate did not arise from greater heating of black skin.

Functions of water. There appear to be at least three quantitative differences between the Aboriginal groups and Europeans in water handling. These are the

(a) rapid intake of large volumes of water by Aborigines,
(b) rapid excretion of water through the kidney, and
(c) higher rates of sweating, with rapid sweat suppression, in Aborigines.

Men of the nomadic desert groups drank more water more rapidly than Europeans. Some of the Aborigines were slower in this performance than others, the slowest usually being the more feeble, aged or inadequate members of the group. Children learn to drink rapidly in the first few years of life. Some of the background of this competence at ingesting 2 ℓ. in 30 - 40 sec may arise from the social pattern. With no easy means of carrying water during hunting a large drink before moving off and a similar intake when a waterhole is encountered would provide water carried in the stomach rather than externally. The shallow water-carrying dishes partly filled with grass to prevent water spillage could also contribute to this pattern in camp. The Ngadadjara women still used the wooden water containers although they had some metal cans. Water brought by the women in the wooden dishes was rapidly consumed by the men and the dishes were turned to other purposes. It seems possible that the rapid ingestion pattern could derive from a conditioned response to taking water while it is available. Certainly the facilitation of swallowing is acquired early and most of the population of men, women and children achieve very high rates of ingestion. In each Aboriginal group studied there was at least one member who did not fall into the general pattern and seemed less competent in hunting, ritual or other activities. He usually was not able to ingest a litre of water in under 30 sec and 2 ℓ. of water was, as amongst the Europeans, beyond his capacity. But the large majority of tribesmen were skilful

at fast drinking. These water loads could provide a reserve during the day, to be drawn upon slowly, since during activity the rate of excretion was reduced and diuresis did not reach wasteful levels.

During cool weather (under 24°C) the Ngadadjara excretion rate did not respond readily to water loading at the rate of 10-20 ml/kg. Europeans, however, showed the standard response of increased diuresis after 15-20 min and the increased water input was excreted within 3 hr. Similar brisk diureses were induced by drinking in cool weather (22°C) by the more acculturated Pintubi. In hot weather, however, the desert people drank more water at dawn and between 6 and 10 a.m. so they had excretory rates 4-10 times higher than those of Europeans. When a standard water load was added, the Ngadadjara and Pitjandjadjara increased excretion more rapidly than Europeans and the added dose of water was excreted within 3 hr whereas the Europeans had lower rates of diuresis and only about half was excreted within 3 hr. A similar pattern occurred in Arnhem Land. With daily temperatures above 30°C the Aborigines seemed to drink more water early in the day and maintain a state of diuresis which was inhibited by exercise. Water intake at night was also high and this showed up as urine volumes of 650 - 700 ml at dawn. It was rare to find a European overnight urine volume of 300 ml during hot weather : usually 230 - 250 ml was produced between 9 p.m. and 6 a.m.

In most animals a high rate of water turnover is associated with increased total body water and extracellular fluid volume (Macfarlane and Howard, 1971). This occurred in all groups of Aborigines. The total body water content was greater than that of Europeans by about 10% and the extracellular volume was relatively even higher. The Ngadadjara thiocyanate spaces were greater than those of the Pitjandjadjara and those in turn greater than the European in the same summer environment. So the high water intakes are reflected in the retention of a potential reserve of extracellular and possibly gut water amongst the desert people.

The relative water use by Melanesians, Aborigines and Europeans in the tropics and the desert are given in table. Coastal Melanesians use more water than Europeans or than mountain Melanesians. Wet tropical Aborigines use more than Europeans in the same environment, but the difference is less than that between the desert Aborigines and Europeans in arid areas during summer.

The body solids (particularly fat) were greater in Europeans in each environment than the solid content of Melanesians or Aborigines. That is the Europeans carried 35 to 131 ml/kg less body water than the other peoples.

When water ingestion ceased at 7 a.m. during hot weather in the desert the Aboriginal urine flow rates were up to 10 times higher than those of Europeans until near noon. With the increments of sweating induced by walking across the desert in the sun, urine flow was reduced in both groups but it was usually not until 3 p.m. that the Aboriginal rates came down near to the low rates achieved by Europeans early in the day. Increases in sweating were associated with and led to the fall in urine flow rate in all groups. Amongst the Aborigines, however, there was an increase in urine flow on cessation of the exercise, while European rates continued to fall, presumably because plasma volume and concentration were low, and aldosterone and vasopressin still active.

In the excretion of sodium and potassium there was a wide divergence between Aboriginal and European renal responses. This showed a sequence of changes

which appeared to relate to degrees of European contact. The Ngadadjaras increased sodium and potassium excretion during exercise in the heat while Europeans reduced the rate of electrolyte excretion to 30% of the initial rate. The Pitjandjadjara in the heat, achieved some reduction in sodium output, but potassium excretion rate was not lowered as in the Europeans. Among the more acculturated Pintubi and Dalbon groups there were some individuals who retained the Ngadadjara pattern, but more of them behaved like Europeans in relation to water and salt retention during exercise in the heat. The mechanism underlying these differences of excretion probably involves the salt concentration of sweat and the volume of extracellular fluid. If there is a high extracellular fluid to be drawn upon for sweating and the electrolyte concentrations in the sweat are low, accumulation of electrolyte in the plasma would occur as dilute sweat (20 mequiv/ℓ.) left the body. Some of the 120 mequiv/ℓ. sodium remaining in plasma would be excreted, in order to adjust the salt patterns of the blood brought about by losses from the extracellular fluid volume. In Europeans with twice the Aboriginal electrolyte concentrations in sweat and with smaller extracellular volumes, the effect of sweating would be to reduce the plasma volume sufficiently to mobilise sodium and water retention, through aldosterone and vasopressin. As the sweat concentrations of electrolytes rose with exposure to European money and food patterns the Aboriginal response to sweating and extracellular fluid dynamics came more to resemble those of Europeans.

Exercise. The cardiovascular responses to exercise differed in the two groups. Although the desert Aborigines spent most of the day during summer sleeping in the shade they were accustomed every day or two to very vigorous exercise during hunting. This required often 10 to 15 km of walking and stalking, as well as running and carrying. When standard exercise was undertaken, the Aboriginal rise of pulse rate was less and the recovery quicker in men of the same age groups as the Europeans. Arterial blood pressures in the desert people were low as had been reported by earlier observers (Nye, 1937, Caseley-Smith, 1959, van Dongen et al. 1962) and these rose less with exercise. The European diastolic pressures during recovery in the heat were considerably lower than those of the Aborigines, presumably because of greater vasodilation. This is associated with an unpleasant feeling of weakness, when ambient temperature is near or above that of the blood (Kronfeld et al. 1958). These observations presumably indicate that the Aborigines were physically fit and had good circulatory resilience. The Pintubi and Dalbon groups had higher resting blood pressures and the rise during exercise was greater than those of the Ngadadjaras, presumably since hunting activities of the former tribes were reduced. None of the peoples studied was as fat as permanent welfare station Aborigines (who eat excessive carbohydrates) since both the Pintubi and Dalbon groups went bush at intervals, lived off the land and preferred some independent existence.

As European contact increased, several gradients of function appeared in the Aboriginal groups. Resting blood pressures were very low in the Ngadadjaras and sequentially higher in the Pitjandjadjara, Pintubi and Dalbon. The rate of ingestion of water was highest in the desert groups and lower in the Arnhem Land Dalbon. During exposure to heat with sweating, the excretion of sodium and potassium was greatest in Ngadadjara less in Pitjandjadjara, Pintubi and least in the Dalbon. The degree of suppression of arm sweat by 1 hr in a saturated environment was greatest in the desert people, less in Pintubi and least in Dalbon. Similarly the sodium concentration of sweat rose progressively with acculturation. Even amongst the

Dalbon, however, sweat suppression was at least 5 times greater than amongst Europeans working with them and the sweat sodium concentration was only about half that of Europeans. Sweat suppression appears to be retained even after town life for some years, and it is retained by Aboriginal-European crosses. The mechanism of suppression is not clear but it could be that the keratin of Aboriginal skin swells to occlude the sweat ducts more than amongst Europeans. Certainly 5-year old children show even more sweat suppression than their elders so that hyperkeratinization acquired from long exposure to sun would not easily account for the suppression. The recovery of sweating rate after 30 min of exposure to dry air suggests a local skin phenomenon and the only simple possibility other than mechanical obstruction of the ducts seems to be an axon reflex type of inhibition of the secretomotor nerves. The considerable degree of suppression makes the testing of acclimatization to heat (32°C) in a saturated environment, difficult to interpret (Wyndham et al. 1964). Probably the test applied by those investigators mainly indicated relative rates of suppression of sweating.

Acculturation. Desert Aborigines appear to survive the rigors of the summer by remaining near water sources, and going without food rather than water. They retain a high rate of water turnover in the desert, associated with rapid ingestion and excretion of water and low osmotic pressures of urine. They are lean and hold relatively high proportions of body water and extracellular fluid. This, together with a rapidly ingested water load of perhaps 4% of body weight, could provide for long journeys even in the heat of summer. Sweating rates are high but the sweat is low in electrolyte content. Protection of black skin from the sun by clothing does not reduce the rate of sweating to that of Europeans so that high sweat rates are apparently not due to higher skin temperatures. Oral temperatures are not readily raised by exercise in the sun.

The desert Aborigines appear to function like other tropical animals (pigs, cattle) with poor water conservation mechanisms. When adapted to the desert Aborigines are, like cattle, behaviourally adjusted to remain near water sources. Mammals evolved in the desert - like the camel - have low rates of water turnover, great salt tolerance, higher urinary concentrating powers and weeks of survival-potential without water. The Europeans working with Aborigines in the desert were nearer to camels in respect of water turnover rate and urine concentration than Aborigines, but because they have less extracellular fluid and less adequate circulatory compensation, Europeans are more likely than Aboriginals to suffer circulatory failure in less than 1 day without water, in the sun.

The skin of Aboriginal nomadic groups reached higher temperatures in the sun than that of white men in the same environment, but virtually all wore clothes. Oral temperatures were in the European range.

SUMMARY

In the desert during summer extracellular fluid volume of Aborigines was greater than that of white men, while the volume of water drunk and the rate at which water was ingested were also greater. Two litres of water were ingested in 34-39 sec by desert Aborigines but Europeans found difficulty with 1.5 ℓ. in 180 sec. Aborigines turned over water at about twice the rate of Europeans in the same environment.

In summer, urine flow rates were several times greater in Aborigines than in Europeans in the same environment. When deprived of water, however, the Aborigines reduced urine output to near the European level. They increased sodium excretion during a day without water in contrast with the European decrease in sodium excretion as water and salt were retained.

The amount of sweat produced in summer when measured by body weight changes was greater in desert Aborigines than in white subjects. The same Aboriginal subjects, however, produced less than half the sweat from arms in the saturated atmosphere of plastic bags, because of more rapid and complete sweat suppression. Sweat suppression was not necessarily reciprocal to heat acclimatization. The summer sweat of Aborigines contained less sodium but more potassium and urea than European sweat.

Standard exercise in the heat raised the low blood pressures of desert Aborigines only half as much as the higher pressures of Europeans. Aboriginal plasma renin was higher than that of Europeans, an anomalous finding.

With increasing European contact Aboriginal arterial pressures rose, but there was reduction in water intake and in the rate of sodium excretion during exercise, while sweat suppression was lessened with acculturation.

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TABLE I.

Exercise tolerance : step test at 37°C DBT 23°C WBT.

Stepping 30 cm at 30/min for 5 min

	Sitting at rest				Recovery			
	Pulse rate	BP	Oral T°C	5 min stepping	Pulse rate 1 min	Pulse rate 5 min	BP 2 min	Oral T°
Pitjandjadjara	72-100	$^{94}/_{56}$-$^{108}/_{78}$	36.6-37.3		112-144	80-116	$^{98}/_{62}$-$^{138}/_{84}$	36.5-36.9
(7) Av.	87	$^{99}/_{69}$	36.8		132	94	$^{116}/_{71}$	36.7
Rise					45	7	$^{17}/_{2}$	-0.1
European	72-104	$^{126}/_{86}$-$^{148}/_{98}$	36.9-37.1		120-165	90-108	$^{160}/_{92}$-$^{218}/_{92}$	36.9-37.1
(3) Av.	85	$^{138}/_{91}$	37.0		142	101	$^{181}/_{81}$	37.0
Rise					57	16	$^{43}/_{-10}$	± 0

Arterial pressures were lower in Pitjandjadjara men (20-60 years); they also rose less on exercise than those of the Europeans (25-64 years). Similarly the pulse rates rose less and returned more rapidly in the Aborigines than among the Europeans, after exercise.

TABLE II.

Water load

Urine flow
ml/min

	6.15-8.45	8.45-9.45	+30 min	+60	+90	+120	+180
Pitjandjadjara (7)	3.2	1.21	2.37	6.78	10.84	7.1	3.3
Europeans (5)	0.31	0.38	0.53	0.82	3.60	1.69	0.59

↑
Water 2% of
body weight

Effect of drinking water in a relatively cool environment (T 28°C) on urinary output of water. The Aborigines began the day with dilute urine flowing at 10 times the European rate. After taking water at 9.45 a.m. there was a rapid diuresis in Aborigines, reaching 3 times the European rate. In 3 hr the Aborigines excreted 1132 ml (more than 2% body weight ingested) and Europeans 233 ml (15% of the load). This ready diuresis of the Aborigines reflects their normal state of over-hydration during summer.

TABLE III.

Day without water

Excretion rate ml/min

	Weight Kg	Urine volume ml/min					Rehydration
		6.15-10.45	10.45-12.30	12.30-3.00	3.00-4.00	4.00-5.20	
Pitjandjadjara (10)	60.7	2.33	1.39	0.47	0.36	0.33	1.0 ℓ. in 21 sec
European (4)	82.9	0.77	0.98	0.39	0.34	0.38	0.75 ℓ. in 30 sec

TABLE IV.

Water loss during walking in the desert sun

Male subjects, February

	Wt.	Urine flow ml/min			Sweating		Na, K excretion % change with 1 hr walk	
		Before	During	After	Wt. loss g/kg/hr	Arm bag ml/kg/hr	Na	K
Morning 29/22°C								
Europeans (5)	82.05	0.38	0.31	0.41	6.6	0.59	-37	+13
Pitjandjadjara(7)	60.30	2.60	1.31	0.9	8.4	0.37	+2	+42
Afternoon 34/23°C								
Europeans (5)	80.6	0.52	0.22	0.34	7.9	0.57	-62	-49
Pitjandjadjara(7)	59.1	0.79	0.58	0.80	8.0	0.35	-31	+13

Pitjandjadjara men had higher rates of urine flow and greater rates of sweat loss than Europeans in the same environment. Arm bag sweat suppression was, however, greater in Aborigines than in Europeans. The first walk of the day reduced European Na excretion (with a 13% increase of K output) while the Aborigines excreted more Na and K. In the afternoon however these partly acculturated Pitjandjadjara men reduced Na excretion, but only to half the extent shown by Europeans, and less K was lost by both groups, than in the morning.

TABLE V.

Day without water in summer

	No.	Urine volume ml/min		Na excretion μequiv/min		K excretion μequiv/min	
		1	2	1	2	1	2
Ngadadjara	7	1.47	0.96	45	69	164	142
Pitjandjadjara	10	1.38	0.78	73	95	36	91
Pintubi	8	1.09	0.76	62	47	30	41
European (Ngada.)	4	0.72	0.32	159	48	87	45
European (Pitj.)	4	0.52	0.27	107	28	57	47
European (Pint.)	3	0.36	0.16	52	9	39	21
Ratio							
Ngadadjara	7	100	65	100	153	100	86
Pitjandjadjara	10	100	57	100	130	100	250
Pintubi	8	100	70	100	76	100	137
European (Ngada.)	4	100	45	100	30	100	52
European (Pitj.)	4	100	52	100	26	100	82
European (Pint.)	3	100	61	100	18	100	54

1 Urine 2 hr in the morning

2 Urine 2 hr in late afternoon

Max. air T^{o} $38^{o}C$

The rate of urine flow decreased through the period without water. Sodium and potassium excretion, however, increased in rate during dehydration. The amount of this increase became less as acculturation of Aborigines increased.

The European controls are named for the groups they were associated with, and the environmental conditions differed somewhat in each situation.

TABLE VI.

Sweat suppression by an armbag (saturated air at $36^{o}C$) in central Arnhem Land

		Left arm continuously in arm bag for 90 min			Right arm, two sessions of 30 min in arm bag		
		0 - 30	31 - 60	61 - 90	0 - 30	31 - 60	61 - 90
Sweat ml/min	E (8)	0.67	0.37	0.31	0.60	-	0.69
	A (9)	0.38	0.13	0.03	0.41	-	0.29
Sodium mequiv/ℓ.	E	44.5	39.2	43.0	44.6	-	60.2
	A	33.6	29.5	30.8	33.3		37.2
Potassium mequiv/ℓ.	E	9.5	7.1	7.8	9.9	-	9.5
	A	9.7	8.0	8.9	8.4	-	8.9

While walking in the sun (dry bulb 36^{o}, wet bulb $27^{o}C$) suppression of sweating was more rapid and complete in adult Dalbon than in Europeans during 90 min continuous wearing of an arm bag (left arm). With 30 min respite from the saturated air of the arm bag (right arm) there was still some reduction of sweat rate by the Dalbon. The differing rates of flow did not, however, affect salt concentration in either group, but the sodium level was lower in Dalbon than in Europeans. On the other hand Dalbon sweat sodium was more concentrated than that of Ngadadjaras and Pitjandjadjaras (Table VII).

TABLE VII.

Volume and electrolyte content of arm bag sweat collected from four Aboriginal groups (adult males) and Europeans in the same environment

		ml/hr	Na mequiv/ℓ.	K mequiv/ℓ.	European contact
Ngadadjara	(16)	7.8	20.6	17.2	±
Pitjandjadjara	(12)	16.5	25.9	8.9	+
European	(17)	37.4	51.0	9.9	++++
Pintubi	(11)	20.4	40.4	8.1	++
European	(4)	40.3	79.5	6.7	++++
Dalbon	(10)	32.3	50.6	10.0	+++
European	(3)	38.3	49.8	9.5	++++

With increasing European contact there was less suppression of sweating in the armbag, and sodium concentrations in sweat rose. In the wet tropics European and Dalbon sweat sodium concentrations were equal. These people lived about half the year in houses on European types of food. There was however still sweat suppression in armbags among the Dalbon.

TABLE VIII.

Mean water content and turnover of Melanesian, Aboriginal, and European adults

	Body water ml/kg	Body solids %	Water turnover* ml/ℓ./24 hr
New Guinea Lat. 6°S			
Tropical island			
Melanesians (17)	645	35.5	114
Europeans (2)	600	40.0	70
Mountains : Melanesians (27)	731	26.9	66
Arnhem Land Lat. 12°S			
Wet tropics			
Aborigines (16)	695	30.5	173
Europeans (3)	618	38.2	130
Central Desert Lat. 25°S			
Aborigines (13)	660	34.0	143
Europeans (4)	617	38.3	86

* Expressed as amount per litre of body water turned over daily, because of differing body solids content in the groups.

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